Assessment of the improvement on the flavour of tap water obtained by advanced treatments

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Evaluación de la mejora en el sabor del agua del grifo obtenido por tratamientos avanzados

Avaluació de la millora en el gust de l'aigua de l'aixeta obtingut per tractaments avançats

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RESUMEN

Las compañías de abastecimiento de agua han centrado tradicionalmente sus esfuerzos en suministrar un producto con garantía sanitaria. No obstante, el consumidor no evalúa el agua teniendo en cuenta normativas sino en términos de sus propiedades estéticas. El sector del agua de consumo humano es consciente de ello y está haciendo un notable esfuerzo en mejorar el olor y sabor del agua. Ello requiere la introducción de tratamientos emergentes, como la oxidación avanzada o las tecnologías de membranas.

Se presentan tres proyectos sobre este tópico: primero, el cambio alcanzado mediante mezcla de recursos tradicionales con agua de mar desalinizada por ósmosis inversa; segundo, el comportamiento comparado de tres carbones activos distintos; y tercero, la influencia global del TDS ("Total Dissolved Solids" o residuo seco) en la percepción del sabor. Se ha realizado un programa de sesiones de cata con voluntarios (panel no entrenado) y un panel profesional (de acuerdo con el método del Flavour Profile Analysis descrito en el *Standard Methods*, de la *American Water Works Association*). Se han realizado dos tipos de experimentos: pruebas de ranking y scoring (puntuación) como técnicas afectivas, y el test triangular de diferencias como herramienta discriminativa.

El presente trabajo muestra claramente la utilidad del análisis sensorial para las empresas del ramo del agua para evaluar la mejora de la calidad del agua obtenida por métodos de tratamiento avanzados.

Palabras clave: Análisis sensorial; agua de bebida; sabor; tratamientos avanzados.

SUMMARY

Drinking water supply companies have traditionally focused their efforts on providing a product with health guarantees. However, the consumer does not evaluate the water by taking into account the regulations but rather in terms of its aesthetic properties. The water sector for human consumption is aware of this and is making a noteworthy effort to improve the odour and taste of water. It requires the introduction of emergent treatments, such as advanced oxidation or membrane technologies.

Three projects about this topic are presented: first, the change achieved by blending traditional resources with desalinized seawater by reverse osmosis; second, the comparative behaviour of three different activated carbons; and third, the overall influence of the TDS ("Total Dissolved Solids") on taste perception. A programme of tasting sessions has been performed with volunteers (untrained panel) and a professional panel (according to Flavour Profile Method described in Standard Methods for Water and Wastewater, from American Water Works Association). Two types of experiments have been performed: ranking and scoring tests as affective techniques and triangle difference test as discriminative tool.

The present work clearly shows the usefulness of sensory analysis for the water utilities to evaluate the improvement on the organoleptic quality of the water obtained by advanced treatment methods.

Keywords: Sensory analysis; drinking water; taste; advanced treatments.

RESUM

Les companyies d'abastament d'aigua han centrat tradicionalment els seus esforços en subministrar un producte amb garantia sanitària. No obstant, el consumidor no avalua l'aigua tenint en compte normatives sinó en termes de les seves propietats estètiques. El sector de l'aigua de consum humà és conscient d'això i està fent un notable esforç en millorar l'olor i sabor de l'aigua. Això requereix la introducció de tractaments emergents, com l'oxidació avançada o les tecnologies de membranes.

Es presenten tres projectes sobres aquest tòpic: primer, el canvi assolit mitjançant barreja de recursos tradicionals amb aigua de mar dessalinitzada per osmosi inversa; segon, el comportament comparat de tres carbons actius diferents; i tercer, la influencia global del TDS ("Total Dissolved Solids" o residu sec) en la percepció del sabor. S'ha realitzat un programa de sessions de tast amb voluntaris (panel no entrenat) y un panel professional (d'acord amb el mètode del Flavour Profile Analysis descrit al *Standard Methods*, de la *American Water Works Association*). S'han

realitzat dos tipus d'experiments: proves de ranking y scoring (puntuació) com tècniques afectives, i el test triangular de diferències como eina discriminativa.

Paraules clau: Anàlisi sensorial; aigua de beguda; sabor; tractaments avançats.

1. INTRODUCTION

The taste of a water depends basically on its mineralisation, the level of total dissolved solids (TDS) and the major ionic species present. There are just four basic tastes (acid, sweet, bitter, and salty) and the detection takes place by means of the buds of the tongue (which are not specifically distributed in some parts of it as has been thought for a long time). Another taste, umami, has been proposed but it is no relevant for water. With respect to flavour, the situation is more complex because it integrates three components: taste perceived in the tongue; feelings or sensations (metallic, pungent, soapy, refreshing, etc) detected in the bucal cavity; and odour detected in the olfactory epithelium through retronasal way (1-3). The borders between these mechanisms are not perfectly defined due to the enormous physiological complexity of human senses (4,5).
Drinking water supply companies have traditionally focused their efforts on providing a product with health guarantees. However, the consumer does not evaluate the water by taking into account the regulations but rather in terms of its aesthetic properties, specially its flavour. The water sector for human consumption is aware of this and is making a noteworthy effort to improve the odour and taste of water. This has required the introduction of emergent treatments, such as advanced oxidation or membrane technologies.
Advanced oxidation methods, such as ozonation and carbon filtration, have been notably useful to improve the overall quality of water by reducing its organic content (6,7,8). In particular, they allow a notable improvement in flavour due to the significant removal of taste-and-odour producing compounds. Membrane technologies also improve the taste of water because they reduce (even completely eliminate) the concentration of organic compounds, and also lower the mineral dissolved solids, which is a benefit in case or medium-high and high mineralised waters (9-12). Anyway, the alteration of the content in the different salts in the permeates has also to be taken into account from the health (13-16) and aggressiveness point of view (17-20).
This paper refers to three different studies where different sensory analysis techniques were applied to evaluate the potential improvement of the quality of the tap water by means of advanced techniques: first, the change achieved by blending traditional resources with desalinized seawater by reverse osmosis; second, the comparative behaviour of three different activated carbons; and third, the overall influence of the TDS on taste perception.

2. METHODS

Tasting sessions
The tasting took place in a room specifically intended for this end, comfortable and free from interfering odours. All samples were duly coded. Flavour was tested in glasses with samples maintained at 25 ºC.

Bench chlorination. All waters were chlorinated at the laboratory at least two hours before the tasting at 0.5 mg/L level of free chlorine. The analysis of the residual free disinfectant was carried out by the N,N-diethyl-p-phenilene-dyamine (DPD) colorimetric method (21).

Panels
Trained and untrained personnel were used, be separately or by means of mixed panels.

Untrained panel. For the tasting sessions with untrained personnel, company employees were called on. These volunteers did not have instruction in sensory analysis nor other special tasting training. They were given no information about the objective of the test either.

Trained panel. It works according to the indications of the Flavour Profile Analysis (21-23). The sensory test used in this study (rating) is not of a descriptive nature (the taste-and-odor wheel is not used) and therefore, it does not require a high degree of training. Nonetheless, the use of a trained panel gives additional value to the study (24,25) and its assessment is estimated to correspond to the most sensitive segment of consumers.

Sensory methods
Both affective (ranking, scoring and scaling tests) and difference techniques (triangle and duo-trio tests) were used (5,26,27). The particular application conditions of the tests were:

*Ranking test***.** Subjects receive n water samples which are to be ranked for overall preference. Data processing consists in giving n points for the one indicated in first place (the best), n-1 for the second one, etc., down to just one point for the worst.

*Scoring test***.** Subjects are asked to rate the overall liking of samples on a given scale, 0 – 10 in this study.

Scaling test. It is similar to rating test, but the panelists "rates" the samples by placing a mark on a linear scale between the left end ("extremely dislike") and the right one (" extremely like").

*Triangle test***.** This difference test consists of presenting groups of three samples, of which two are identical and asking to identify which one is different. The test was carried out in its forced choice option (the tasters had to compulsorily give an answer independently of their degree of certainty).

The panellists were given the opportunity to optionally indicate whether the sample identified as different was better or worse than the other two. This type of test (preference after difference or "difference + preference") is very interesting from the theoretical point of view, but its reliability has been questioned because there is a natural tendency by the subjects to penalize the sample identified as different.

*Duo-trio test***.** An identified reference sample is presented, followed by two working samples, one of which matches the reference sample. The tasters have to indicate the sample that matches. The option to give the "difference + preference" response was also offered to panelists.

The order of presentation of samples in all tests was balanced. Additionally for the difference tests, the proportion of the two waters to be distinguished was also balanced.

3. ASSESSMENT OF BLENDS WITH DESALINATED SEAWATER

Desalination of seawater has revealed to be an extremely useful tool to provide ~~with~~ significant amounts of freshwater to arid coastal areas. Permeates from membrane treatments are extremely low in salts, so it is necessary to pay attention to two main points: aggressiveness and taste of the produced water, both of them being controlled by a proper remineralisation. Blending with local freshwater sources has been recommended as a good choice (28-30). The study was focused on a distribution network with two traditional freshwater sources, one of medium mineralisation (A) and the other with a higher level of dissolved solids (B). The management forecast for the distribution system included additional resources availability from a Sea Water Reverse Osmosis (SWRO) desalination plant.
Preliminary experiments were performed to evaluate the changes in perception by consumers when blended waters would be distributed in the area currently receiving water B.

Experimental
Three samples were tasted: a blend of RO desalinated seawater and B water (50/50), and the traditional waters A and B. Their compositions are showed in table 1.

Scoring and ranking tests were performed. Also duo-trio and triangle tests were used to evaluate the capacity of discrimination between the blend and water B. Both panels were used.

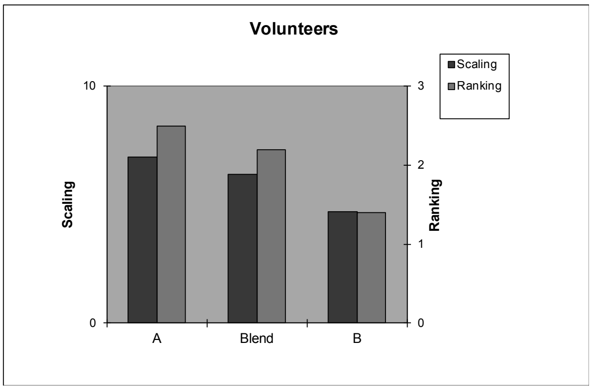
Results and assessment

The results of ranking and scaling tests showed a similar overall evaluation for both panels: the blend with RO water improves the water currently distributed in the B area, while A water continued to be the most appreciated. The difference tests performed clearly indicated that blend could be discriminated significantly from water B.

The "difference + preference" results in triangle test agreed satisfactorily with those from ranking and scaling tests. On the contrary, this concordance was not obtained between these results in duo-trio test. Probably, this fact was due to a misinterpretation in the explanations on how to perform the test and filling of the worksheet; this test is seldom used in our laboratory. Anyway, the main conclusion about the capacity of discrimination between the two waters is not affected at all by this circumstance.

Table 1. *Physico-chemical quality parameters of the waters tasted.*

	Blend 50/50	Water A	Water B
Turbidity (NTU)	0.27	0.23	0.25
Colour (mg Pt-Co/L)	<2	<2	<2
TDS (mg/L)	610	270	1110
Hardness (mg $CaCO_3$/L)	280	180	500
Sodium (mg Na/L)	105	22	181
Chloride (mg Cl/L)	198	33	353
Sulfate (mg SO_4/L)	97	48	215
TOC (mg C/L)	1.7	2.2	2.7



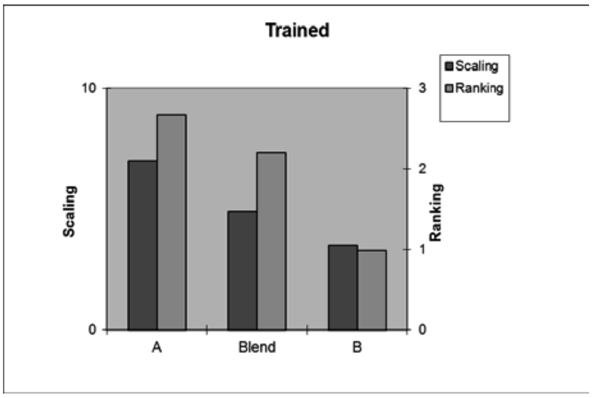


Figure 1. *Ranking and scaling results from both panels, volunteers and trained*

Table 2. *Triangular test results between the blend and reference water B.*

Sample	Type of panel	Test	Subjects (n)	Correct responses	Significant difference?	Any preference?
Blend vs Water B	Volunteers	Duo-trio	49	34	Yes	No**
	Volunteers	Triangular	42	22	Yes	Yes, blend
	Trained	Triangular	50*	40	Yes	Yes, blend

**: 16 trained tasters available, participating in different sessions.*
***: Explanation given in the text.*

4. COMPARATIVE BEHAVIOUR OF THREE ACTIVATED CARBONS.

Activated carbon stages are very common in drinking water treatment plants (DWTPs) to reduce the global organic content of finished water, natural occurring matter (NOM) as well as organic matter from anthropogenic origin. In addition, it is considered the most broad spectra efficient treatment to remove taste-and-odour compounds (31,32). In fact, nowadays it should better be considered a "classical" method instead of an "advanced" one. The most common treatment is depth filtration with granular activated carbon (GAC), although the addition of powdered active carbon (PAC) is also used specially for discontinuous use, in special circumstances, for example to solve pollution episodes or taste and odour events in the resources. This technique is cost-effective, simple to operate and sustainable because carbon is recyclable through thermal regeneration.

Manufacturers are progressively developing new products with improved performance, basically carbon from different origins dully pulverized and re-agglomerated with suitable binders. Coconut-based carbons, obtained from different parts of the tree (shell, husk, coir pith, and others) are being notably developed due to their availability and good adsorption properties (33).

A bench study was performed to compare the chemical efficiency of 3 different GACs and the flavour of the filtered water: the current product (CP) being used in a real DWTP consisting on a high grade bituminous coal; and two alternative products, a new high density coal (HDC) and a coconut shell carbon (CS).

Experimental.

Scoring tests were performed on carbon filtered waters corresponding to the three different carbons. Results were normalised against high quality reference water. Additionally, triangular test was used to compare the two alternatives with the current product. Only the trained panel was used in this study.

Results and assessment

No significant difference was deduced in both tests for sensory analysis (figure 2 and table 3). On the other hand, the study on physic-chemical quality of treated waters did not show significant improvement by using an alternative. Therefore, the water utility was advised not to introduce changes in the process. The non-significant improvement with the products tested does not imply that future developments in the manufacturing of filtration materials are not capable to offer new improvements to water treatment sector.

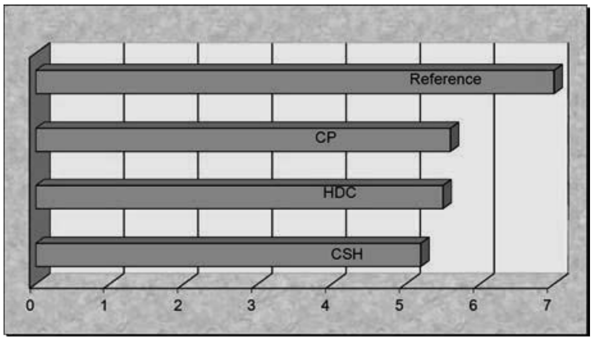


Figure 2. *Scoring test results for three carbon filtered waters (CP, HDC, CSH). Results were normalised against a high quality reference.*

5. FLAVOUR IMPROVEMENT BY REVERSE OSMOSIS

In addition to considerations about the availability of new water resources, membrane technology has shown to be useful to improve the flavour of water by two main reasons: first, it removes undesirable organic compounds not relevant for the sanitary condition of the water but causing offensive taste and odours; and second, it allows reducing the mineral content of the product, which is a noticeable improvement when medium to high mineralized waters are treated.

Some WTPs just treat by membranes a part of the flow. The higher the percentage of membrane-treated water, the lower the salinity (conductivity) of the finished water is. Although the cost of the membranes treatment has been reduced in the last years due to the efficient energy recovery systems in desalination plants (34,35), it's still more expensive than conventional treatments. For this reason, it is crucial for water supply companies to know the relationship between liking and the mineral content of the waters supplied.

Experimental

Waters at eight conductivity points between 160 and 1000 mg/L were tasted in several sessions by a mixed panel (trained + volunteers). The samples were prepared by proper dilution with deionised water of the finished water from a WTP fed with a high salinity source, in different days. Results from different sessions were normalised against a reference water to be comparable.

Results and assessment

A high variability in individual responses was observed, but the mean values (corresponding to 34 – 44 scores per water) showed a clear decrease of liking as conductivity (salinity) increases (figure 3). The high variation between individuals indicated the subjective character of the taste of water.

Table 3. *Triangular test results between two alternative carbons (HDC, CSH) and the reference product (CP).*

Sample	Type of panel	Test	Subjects (n)	Correct responses	Significant difference?
HDC vs CP	Trained	Triangular	12	4	No
CSH vs CP	Trained	Triangular	13	5	No

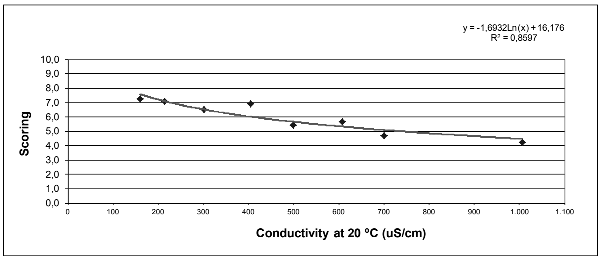


Figure 3. *Overall liking vs conductivity for tap water*

6. CONCLUSIONS

The results of this work allow confirming the usefulness of a combination of affective and difference sensory analysis techniques to assess the improvement on the tap water flavour that can be achieved with the new technologies that the water supply sector is applying. Results from three different studies are reported.

Blending of a high TDS source with desalinated water has proven to be an efficient procedure to improve the taste of the supply.

No sensory difference has been noticed between the organoleptic quality of water being filtered through three different activated carbons. This fact was in accordance with results from the physico-chemical study. The non-significant improvement with the products tested does not imply that future developments in the manufacturing of filtration materials are not capable to offer new improvements to water treatment sector.

Total dissolved solids (or, alternatively, conductivity) show an important influence on average liking of drinking water. The present study covered conductivities between 150 and 1000 μS/cm (TDS from 100 to 650 mg/L approximately), and showed a substantial decrease of liking as salinity increased. On the other hand, the high variation between the individual preferences indicates the subjective character of the water taste assessment.

Although a certain knowledge about the role of the cations and anions in solution on water taste is available (23,25), more research is needed in this complex topic.

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